SDS advanced hybrid computation

SCIENTIFIC DATA SYSTEMS

SDS ADVANCED
HYBRID COMPUTATION

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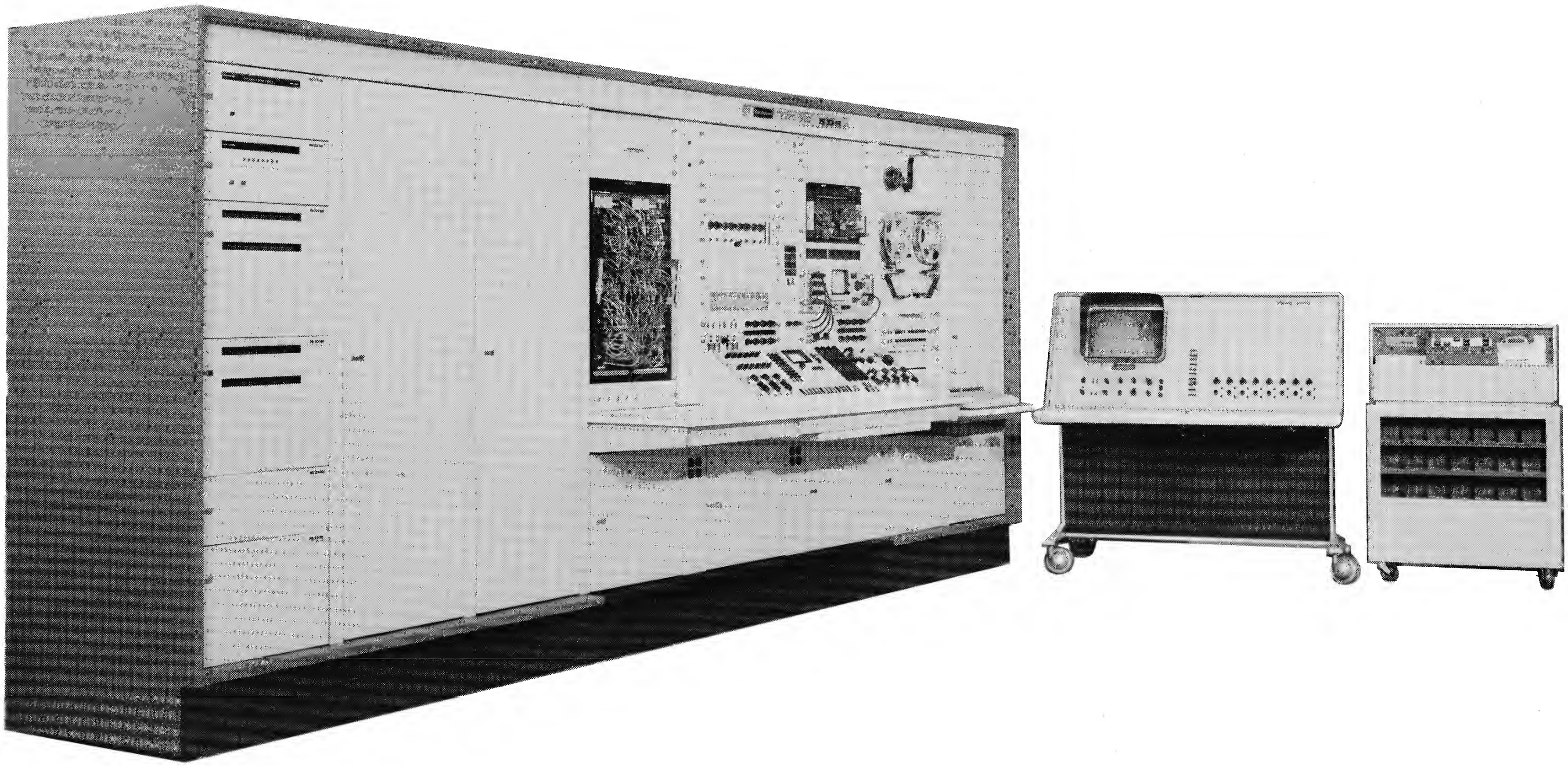
SCIENTIFIC DATA SYSTEMS/1649 Seventeenth Street/Santa Monica, California/UP 0-5471



Beckman/SDS 2200/920 Hybrid Computing System

FOREWORD

Hybrid computing systems have grown out of the need for combining the accuracy and flexibility of digital computers with the speed of analog computers in solving many classes of problems, particularly in the field of simulation. The hybrid computer offers a natural course of growth and expansion that lets the user take full advantage of his analog computer. The professional staff at Scientific Data Systems has pioneered the application of digital techniques to hybrid computation, beginning with the development of the digital differential analyzer. Drawing on this experience, SDS has developed the most advanced line of hardware and software for hybrid computation currently available. This line includes six compatible digital computers, the DES-1 Differential Equation Solver, HI Series Hybrid Interface Equipment, a complete line of analog/digital conversion equipment, and a comprehensive set of Hybrid Computation Software. SDS can provide a truly integrated hybrid computing system with most analog computers in use today.

SDS general-purpose digital computers (SDS 92/910/920/925/930/9300) are designed for easy integration into hybrid systems. In addition to their high internal computing speeds and powerful instruction repertoires, these computers include several other features that are particularly useful in hybrid computation. All six computers have a large, multilevel priority interrupt system with each level having a unique priority and address in memory. These interrupts permit the analog computer to signal the digital computer at any time during the course of a problem. All six computers can send and receive large numbers of control and sense signals completely independently of normal input/output channels and include a word parallel input/output system that provides a communications bus for control and data signals.

SDS HI Series Hybrid Interface Equipment provides the necessary linkage to insure efficient and economical operation of both analog and digital components of hybrid computing systems. This linkage equipment provides facilities for bidirectional communication of data, control signals, information, and status indication. The analog/digital conversion portions of the linkage consist of standard SDS converters and multiplexers that make extensive use of integrated circuitry. This equipment permits conversions at rates up to 80,000 conversions per second and operates in either random or sequential selection modes.

The SDS Hybrid Programming Library permits fully integrated operation of hybrid computing systems. This software, which persons with a minimum of training in digital computer programming can use, provides complete control over system hardware with no loss of response time. It provides the means for analyzing and setting up problems and for insuring that the system operates properly during problem execution. This software is operational with two hybrid systems: one used by the government and one by a large aerospace company in the Apollo program.

As a part of its continuing development program in hybrid computation, SDS will offer courses in hybrid computation, including the use of the SDS Hybrid Programming Library and of the DES-1 Differential Equation Solver. These courses, which begin in January 1965, will be taught by experts in the field. Class size will be limited so students can gain ample actual operating experience with hybrid computing equipment.

1. BACKGROUND

Development of the electronic differential analyzer, or analog computer, in the early 1950s, made it possible to solve a large class of problems for the first time. This was because of the analog computer's ability to integrate variables directly, to perform all operations in parallel, and to solve simultaneous sets of nonlinear differential equations in real time. Some of the more important early applications of the analog computer included its use in designing servo systems, in investigating dynamics of flight, in performing nuclear reactor studies and random process studies, and in controlling various processes. In the design of aircraft control systems alone, the analog computer has been of invaluable assistance to systems engineers and designers.

From the beginning, however, the shortcomings of the analog computer were apparent. In particular, the accuracy of the solution in an analog computer is bounded by the physical components used. For example, in performing a single linear operation, 0.01 percent of full-scale accuracy can be achieved; but in a typical problem, where many linear and nonlinear operations are carried out, the final accuracy of the solution generally ranges between 0.5 percent and 5.0 percent of full scale. Other shortcomings inherent in the analog computer are limited memory capacity, difficulty in performing logical operations, lack of extended time delays, limited ability to handle nonnumeric information, and the impracticality of generating multivariable arbitrary functions.

The digital computer was developed concurrently with the early analog machines. Although the digital computer is an extremely powerful tool, its early application to simulation problems was very limited because of the need for a real-time response of the computer in most simulated systems. Although this limitation still exists to some extent, today's digital computers are faster, more powerful, and less expensive so that they can be used effectively in many real-time simulations.

It became obvious that a combination of analog and digital computers could be used to overcome the limitations of all-analog or all-digital simulation. Such combined computers, called hybrids, removed most of these limitations and made possible the solution of complex problems that were practically unsolvable before. With a hybrid computer, parts of a problem requiring a high degree of accuracy, logical and mathematical manipulation, automatic scaling, and storage of large amounts of data can be solved on the digital portion; parts of the problem requiring speed and parallel operation, real-time integration of variables, and having continuously varying parameters can be solved on the analog portion.

The earliest attempts at hybrid computation were made in 1958 at Convair Astronautics, San Diego, and Space Technology Laboratories, Los Angeles. Certain members of the present SDS staff participated in the development of these early systems. Since that time many computer laboratories have combined analog and digital computers into hybrid systems. Not only have hybrid computers successfully solved the problems for which they were originally designed but whole new areas of application have been entered. Applications in which hybrid computers are being used today include:

1. Simulation studies involving systems having both high- and low-frequency characteristics

2. Systems of differential equations that are solved at high speed for optimization studies

3. Sampled data or computer-controlled systems simulations requiring the combination of continuous and discrete variables

4. Systems requiring real-time statistical analysis, data filtering, smoothing, editing, etc.

5. Systems with transport delays

6. Systems whose solution requires Monte-Carlo or Random Walk procedures.

7. Investigations requiring complex function generators, especially those involving functions of two or more variables

8. Systems described by large sets of simultaneous ordinary differential equations

9. Partial differential equations of the type found in chemical and nuclear processes.

With the growth in the number of hybrid computer installations came the realization that, over the life of the equipment, programming costs exceed the initial hardware investment several times over. For this reason, a programming system that minimizes the day-by-day programming costs is an essential element of any hybrid computing system. To be useful to the engineer engaged in real-time hybrid computation, the software must be easy to run, easy to understand, and useful in every aspect of the problem-solving process from problem design, through setup and problem checkout, to problem running. It must be usable by the engineer who has minimum training in digital computer programming, but flexible enough so that the highly skilled engineer is not overly restricted. It must provide complete control over all system hardware with no loss in speed. In other words, the software must not penalize the response time of the system to external stimuli that are varying in real-time.

Recognizing the importance of software to the hybrid computer user, SDS has formed a special group to work in this area and in analog and digital simulation techniques. Members of this group include specialists in analog and digital simulation and several programmers with experience in programming real-time systems and digital differential analyzers. The software being developed by this group assures the SDS hybrid computer user that he will obtain maximum performance from both the digital and analog portions of his system.

Besides developing programs and techniques for hybrid computer systems, the group is also working with the SDS DES-1 Differential Equation Solver, a general-purpose digital computer (the SDS 9300) programmed and operated using analog methods.

2. HYBRID PROGRAMMING LIBRARY

The problems of effectively using a hybrid computer are manifold. Starting with the description of the problem in equation or block-diagram form, the simulation engineer must arrive at a systems hardware and software configuration that provides the most efficient and economical solution. But, before the problem can be put on the computer, many questions that are basic to hybrid simulation must be answered.

First, how does the engineer decide which parts of the problem are best suited for solution in the digital domain? In a complex simulation, intuition is not an adequate technique for resolving this basic question. Then, in what language should the digital program be written? Is it practical to program using an algebraic compiler, or must the programmer resort to machine language to perform certain functions? And what should be done about timing, arbitrary function generation, integration, and all of the other problems unique to the particular simulation? These questions must be answered before the problem can be set up on the hybrid computer.

Once the problem is running on the computer, how can the engineer be certain that the hardware is working properly? Sufficient maintenance and diagnostic aids must be available to check all aspects of the system (analog, linkage, and digital). Finally, is the analog computer scaled and wired correctly?

The SDS Hybrid Programming Library is designed to answer these questions efficiently and to relieve the hybrid computer user of the burden of unnecessary programming. This open-ended and continuously growing library currently consists of the following major groups:

- HS-10 Problem Analysis Group
- HS-20 Problem Generation Group
- HS-30 Hardware Control Group
- HS-40 System Checkout Group
- HS-50 Input/Output Group
- HS-60 Hybrid Applications Group

The hybrid computation software is designed for general use with all SDS computers. Use of some of the digital programming languages such as FORTRAN IV, Real-Time FORTRAN, and the DES-1H Compiler, however, is limited by memory requirements and the particular computer configuration. Detailed information on these languages is covered in other SDS literature.

HS-10 PROBLEM ANALYSIS GROUP

The Problem Analysis Group consists of:

- HS-10.1 Polynomial Root Finder
- HS-10.2 Z-Transform Coefficient Generator
- HS-10.3 Lagrange Polynomial Coefficient Generation
- HS-10.4 Least-Squares Polynomial Coefficient Generation
- HS-10.5 Chebyshev Polynomial Coefficient Generation
- HS-10.6 Matrix Operations
- HS-10.7 Linear Interpolation Table Generator

Programs in this group are designed for off-line use by the hybrid programmer in deciding which parts of the problem are to be done on the digital computer and what mathematical techniques should be used. For example, the programmer uses the HS-10.1 Polynomial Root Finder to locate the poles and zeros of linear-transfer functions so that he can determine the frequency content of the system. From this information, he specifies which parts of the problem are to be solved on the digital computer and which on the analog.

Particular emphasis is placed on function-generation techniques in more than one dimension since this requirement occurs frequently in large-scale simulations. Multivariable function generation is extremely difficult to perform on the analog computer but well suited to digital solution.

HS-20 PROBLEM GENERATION GROUP

The Problem Generation Group consists of:

HS-20.1	SDS FORTRAN IV
HS-20.2	SDS Real-Time FORTRAN
HS-20.3	SDS META-SYMBOL
HS-20.4	SDS DES-1H Compiler
HS-20.5	Function-Generation Subroutines
HS-20.6	General Mathematical Subroutines
HS-20.7	Hybrid Mathematical Subroutines

This group is the heart of the hybrid library. It consists of four programming languages and special subroutines that are used at run time. The multiple choice of programming languages gives the operator a wide latitude in programming techniques based upon his skill and the constraints of the problem. The programmer can effect a trade-off between solution time and required memory size by using a mixture of programming techniques in the same problem.

SDS FORTRAN IV, a comprehensive algebraic language, allows the hybrid programmer to concentrate on the problem to be solved rather than on operational details of the particular digital computer. SDS FORTRAN IV is a superset of previous FORTRAN systems in that greater flexibility has been added to the language, and many previous FORTRAN restrictions have been removed. SDS Real-Time FORTRAN provides modifications and additions to FORTRAN that allow the system to operate with real-time interrupts.

SDS META-SYMBOL, a symbolic programming language, permits a high degree of programming sophistication. In its most elementary form, the language syntax parallels that of machine instruction format. The language's sophistication, however, allows the use of very generalized programming concepts and lets the user refer to constants, variables, and other parameters in symbolic form. META-SYMBOL is faster, easier to use, and much more powerful than conventional assembly programs.

The DES-1H Compiler, which is the hybrid version of the DES-1 Compiler, allows all of the generality of the DES-1, as described in the SDS DES-1 Brochure, with the added linkages required to operate in a hybrid environment. The use of the DES-1H Compiler is, however, limited to those hybrid configurations that include an SDS 9300 Digital Computer and the SDS DES-1 Console.

The DES-1 has been designed to give the analog computer user a familiar tool. Of particular importance are the DES-1 language and syntax used to express computation and control statements. They allow the user to describe his problem in block-diagram form and in convenient arithmetic notation. When describing a part of the problem in block-diagram form, each block has an associated operator representation in the DES-1 language. The block diagram on the following page illustrates a few typical relationships and is described by the operator list:

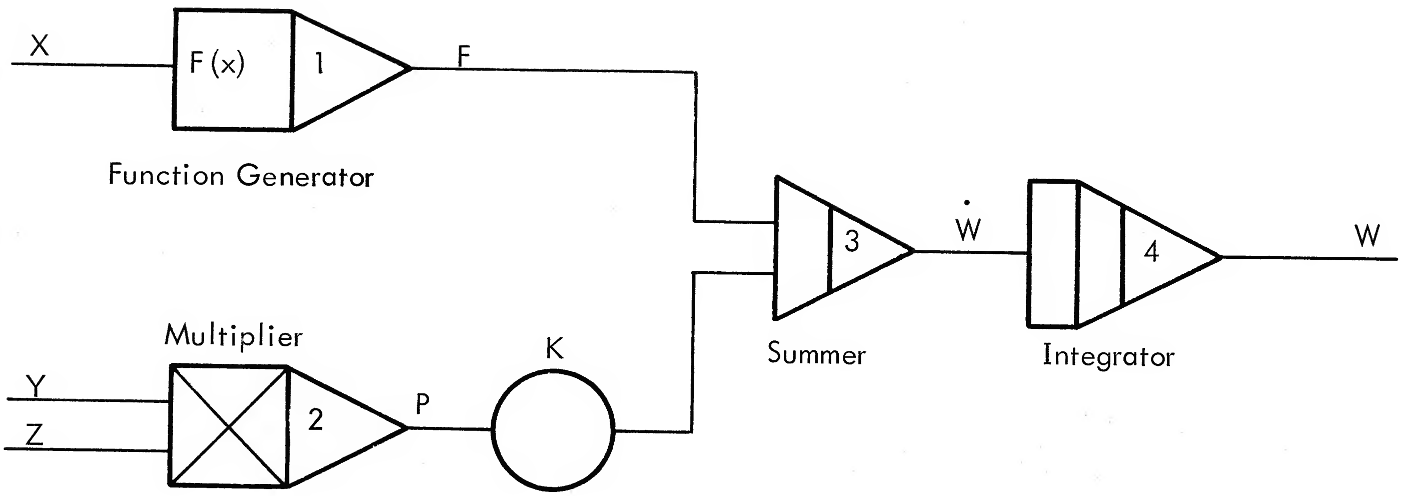
1. FUN X = F

2. MUL Y, Z = P

3. SUM F, K*P = WDOT

4. INT WDOT = W

In addition to the operators indicated in the example, the DES-1 provides operators that duplicate all of the normal analog functions. Of greater importance, however, the DES-1 also provides the logical decision ability and memory features of a general-purpose digital computer.



HS-30 HARDWARE CONTROL GROUP

The Hardware Control Group consists of:

- HS-30.1 Generalized Analog Control
- HS-30.2 DO/IT Control Program
- HS-30.3 ADIOS Control Program
- HS-30.4 Time Base Generator
- HS-30.5 Analog-to-Digital Conversion Control
- HS-30.6 Digital-to-Analog Conversion Control

This group is used by the program at run time and provides the control and communication between the various elements of the hybrid system. All of the analog computer modes can be selected by the program or through manual intervention from the console typewriter. Operation of automatic features on the analog computer (i.e., potentiometer set, readout, interval timer, etc.) is made available to the programmer in a similar manner. Control of the analog/digital linkage system as well as single-bit input/output channels is handled with the software supplied as part of this group. The format of these programs is such that minimum training is required before the analog-trained programmer can use them. For example, the SDS DO/IT Control Program (HS-30.2) operates in the same way as the Beckman DO/IT system. Typical commands that can be entered from the console typewriter are:

Command	Action
S XXX YYYY	Pot XXX is set to value YYYY.
A XXX	Amplifier XXX is selected and its output voltage is typed out in the format: A XXX ±YY.YY
A XXX YYY	Amplifier values XXX through YYY are typed out.
A	All amplifier values are typed out. (Typeout of all analog elements is performed in a similar manner.)
I	Place analog computer in Initial Condition Mode.
C	Place analog computer in Compute Mode.
H	Place analog computer in Hold Mode.
P	Place analog computer in Pot Set Mode.
D	Disconnect digital computer.

HS-40 SYSTEM CHECKOUT GROUP

The System Checkout Group consists of:

- HS-40.1 Analog Problem Static Check
- HS-40.2 Digital Utility Programs
- HS-40.3 Analog Maintenance and Diagnostic
- HS-40.4 Interface System Maintenance and Diagnostic
- HS-40.5 Digital Maintenance and Diagnostic
- HS-40.6 SDS Apache

This group provides for the checkout of system hardware as well as analog wiring and the digital program. In conjunction with a standard, wired analog patchboard, it is possible to perform all normal maintenance checks of the system hardware. Also provided as part of this group are digital utility programs (i.e., memory dumps, trace, register snapshot, etc.), and the analog static check program. The input to the static check program is a description of the analog patchboard wiring diagram. The program calculates the value of voltages that should appear at the output of the various computer elements. The actual values are measured and compared with the computed value, and the operator is informed via the typewriter if any significant differences occur.

SDS Apache is used to generate analog computer programs with a digital computer. It translates inputs such as equations and maximum values of variables into scaled analog wiring diagrams. This relieves the programmer of the tedious job of manually scaling the problem and its mechanization and virtually eliminates the possibility of error. Apache also automatically prepares documentation and generates static checks.

SDS Apache is designed to allow the specification of the particular analog computer being used. Provision is made for differences between various analog computer models and the number of operational elements contained within a particular system. Several standard analog computer configurations are supplied with Apache, and the user can generate his own specifications for custom analog systems.

HS-50 INPUT/OUTPUT GROUP

The Input/Output Group consists of:

- HS-50.1 System Monitor
- HS-50.2 Oscilloscope Display
- HS-50.3 Special Devices Subroutines
- HS-50.4 Conversion Subroutines

The System Monitor provides necessary operating aids for loading programs, including their library routines, and scheduling jobs. Programs in this group also control operation of analog/digital conversion equipment and special devices such as an oscilloscope display or a digital plotter.

HS-60 HYBRID APPLICATIONS GROUP

The Hybrid Applications Group consists of:

- HS-60.1 Standard Atmospheric Functions
- HS-60.2 Three-Axis Coordinate Transformation
- HS-60.3 Time Delay Subroutine

This group contains special programs that have widespread use in the simulation field. These programs originate from two sources: the SDS hybrid applications section and the users themselves. They include demonstration and acceptance test programs that have been checked out and documented. Through the SDS Users' Group, programs developed at one facility are made available to all SDS users. In addition to the interchange of programs, the biannual meeting of the SDS Users' Group allows an interchange of ideas and direct feedback of user ideas to SDS.

3. HYBRID INTERFACE

In the operation of a hybrid computer system, the characteristics of the interface equipment are as important as those of the computers. SDS HI Series Hybrid Interface Equipment is designed to integrate any SDS computer and any modern, general-purpose analog computer into a unified hybrid entity. This modular equipment assures the efficient and economical operation of the hybrid system. A typical hybrid-system configuration entailing use of this equipment appears on page 8.

The basic functions performed by the hybrid interface are:

- Control Signal and Information Transmission
- Analog-to-Digital Conversion
- Digital-to-Analog Conversion
- Status Sensing
- Priority Interruption

COMPUTER INTERFACE CHARACTERISTICS

Two input/output systems, available with all SDS computers, provide the basic communication paths used by the hybrid interface. These are the Word Parallel Input/Output System and the Priority-Interrupt System.

The Word Parallel I/O System provides a bus structure for the transmission of data, control and sense signals, and timing signals. Data is transmitted in parallel in the form of 24-bit words. Up to 4096 single-bit sense and control signals can also be transmitted. These signals select devices, sense external status, set or reset switches, or initiate a sequence of operations. Some of the single-bit sense and control lines are terminated at the analog computer patchboard to provide the programmer with a flexible means for testing external conditions and outputting control signals. Analog computers with patchable digital logic use these signals.

The priority-interrupt system provides a large number of interrupt levels, each with a unique priority and address in memory. The SDS computer always processes the highest active interrupt and returns to the main program only when all interrupts have been processed. These interrupts, which are terminated at the analog computer patchboard are particularly useful in time-dependent problems. They signal the digital computer when the problem starts, maintain time synchronization between analog and digital computers, and notify the digital computer of random events that occur in the analog machine. The programs generated by the compilers and assembler of the Problem Generation Group also use the interrupt system.

BASIC HYBRID INTERFACE

The Model HI21 Basic Hybrid Interface is the basic element in the linkage system. It serves as a junction box between the SDS computer and other system units such as conversion control, analog computer control, clocks, displays, etc. The Model HI21 provides complete power supply isolation between analog and digital computers. All signal lines from the digital computer are transformer-coupled and the Model HI21 operates from a separate power supply referenced to the analog computer ground. This eliminates ground loops in the hybrid system and results in "clean" analog signals.

DIGITAL-TO-ANALOG CONVERSION CONTROL

The Model HI31 Digital-to-Analog Conversion Control provides control, timing, selection, and gating functions for up to 128 digital/analog channels. The Model HI31 is used in conjunction with SDS D/A Converters that make extensive use of integrated circuits. A 15-bit converter (14 bits plus sign) operates at a rate of 100,000 complete conversions per second, with an accuracy of ±0.015 percent; buffer registers

provide simultaneous updating of all channels. Optional Operational Amplifiers provide ±100-volt output.

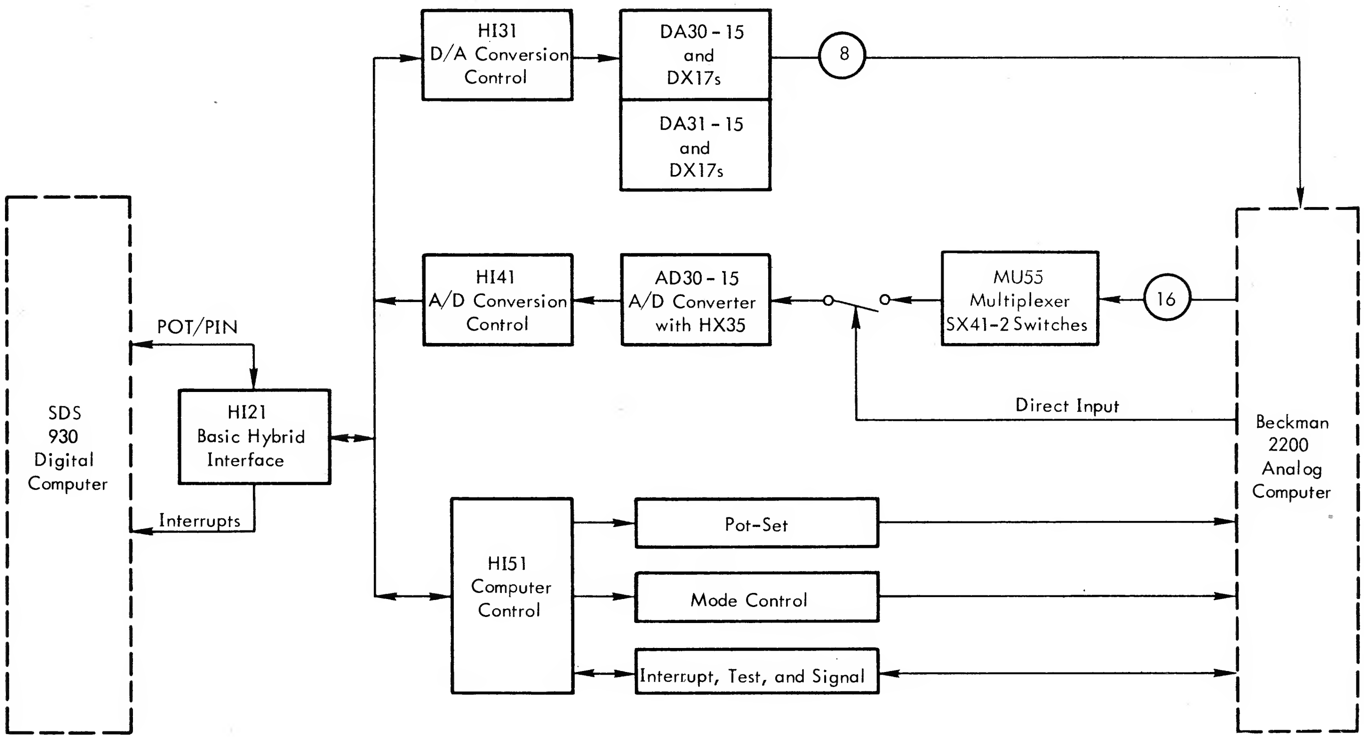
ANALOG-TO-DIGITAL CONVERSION CONTROL

The Model HI41 Analog-to-Digital Conversion Control provides control, selection, timing, and gating functions for up to 128 multiplexed analog/digital channels. The Model HI41 is used in conjunction with SDS integrated circuit A/D Converters, Sample-and-Hold Amplifiers, and Multiplexers. A 15-bit converter (14 bits plus sign) operates at a rate of 42,500 conversions per second, with an accuracy of ±0.01 percent; with a sample-and-hold amplifier and a multiplexer it accomplishes 30,000 conversions per second with an over-all accuracy of ±0.04 percent.

ANALOG COMPUTER CONTROL ADAPTERS

SDS HI Series Analog Computer Control Adapters have been developed for several analog computers, including the Beckman 2200, ADI 256, and EAI 231. These adapters provide control and data transmission paths so that the analog computer can be controlled by the SDS digital computer. The adapter converts all logic levels and pulse shapes to meet the requirements of the analog computer. These functions performed by the adapter depend upon the particular analog computer, but in general it gives the SDS digital computer control over the following analog computer operations:

- Mode Control
- Automatic Pot Setting
- Computing Element Selection
- Digital Voltmeter Readout



SCIENTIFIC DATA SYSTEMS / 1649 Seventeenth Street / Santa Monica, California / Phone: (213) UP 0-5471

SALES OFFICES

NORTHEAST
125-10 Queens Blvd.
Kew Gardens, N.Y.
(212) LIggett 4-9898

69 Hickory Drive
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(617) 899-4700

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WEST
1649 Seventeenth St.
Santa Monica, Calif.
(213) UPton 0-5471

Fountain Professional Bldg.
9000 Menaul Blvd., N.E.
Albuquerque, N. Mex.
(505) 298-8009

Sunnyvale Office Center
505 West Olive Ave.
Sunnyvale, Calif.
(408) 736-9193

FOREIGN REPRESENTATIVES

EUROPE
CECIS
14 Rue de la Baume
Paris 8, France

CANADA
INSTRONICS, Ltd.
P.O. Box 100
Stittsville
Ontario, Canada

JAPAN
F. Kanematsu & Co. Inc.
Central P.O. Box 141
New Kaijo Bldg.
Marunouchi
Tokyo, Japan

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RACAL Pty. Ltd.
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N. Sydney NSW, Australia

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